



# ILLINOIS NATURAL HISTORY SURVEY

## T E C H N I C A L   R E P O R T

### Modeling Waterfowl Migration Using Radar Imagery

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## **Executive Summary**

We examined turnover and stopover duration in dabbling ducks at a major wetland complex in the Illinois River Valley during the fall. Using weather surveillance radar data collected at the KILX radar in Lincoln, Illinois, we estimated the total number of waterfowl emigrating from the study site throughout the fall migration in 2005 and 2006 (October-December). We estimated the average stopover duration across an entire migration by dividing estimates of total use-days (derived from INHS aerial inventories) by estimates of the total number of ducks departing the same site (derived from radar) for each year. We detected 20 departure events in 2005 totaling approximately 401,758 dabbling ducks, and 23 departure events in 2006 totaling approximately 601,968 ducks. Preliminary calculations indicate the average stopover duration for all dabbling ducks was 9 days in 2005, and 6 days in 2006. These initial calculations indicate that the duration of stopover among dabbling ducks in the fall may be substantially shorter than 28-day estimate used for JV mid-migration objectives.

Additionally, we examined 3 wetland complexes in Illinois using weather surveillance radar data collected at KILX from October 1-December 31, 2005-2006 to determine the timing of discrete dabbling duck departures throughout each fall. We compiled a database of biologically-relevant weather observations and constructed a set of competing biological models that will be analyzed using an information theoretic approach to model variation in daily emigration probability and determine the magnitude of the effects of specific environmental conditions. Our initial analysis of radar-derived departure data revealed a high level of synchrony in the timing of departure among dabbling ducks from independent stopover sites. We also identified temporal clusters of departures that correspond with the 2-3 day cycles of regional weather in the Midwest. These two observations provide local, empirical evidence of a

measurable relationship between proximate environmental conditions and emigration in dabbling ducks. Our future analysis will quantify which weather conditions have the greatest effect on the probability of daily departure of ducks from stopover sites, and what the magnitude of their effect is.

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### **Disclaimer**

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Fish and Wildlife Service or Illinois Department of Natural Resources.

### **Objectives**

- 1) Determine if exodus events recorded by WSR-88D may be used to estimate turnover rates (stopover duration) of migratory waterfowl in Illinois.
- 2) Evaluate the potential to model waterfowl migration movements documented by WSR-88D in relation to high-resolution environmental covariates and thereby predict waterfowl egress events in Illinois.

### **Estimating Stopover Duration of Migratory Waterfowl in Illinois**

Every year the wetlands of the Midwest serve as critical stopover habitat for millions of

migrating ducks (Bellrose 1980). Research from the last two decades has elucidated the importance of migration and stopover in the annual life-cycle of waterfowl (Haramis et al. 1986, Hepp et al. 1986, Heitmeyer 1988). However, conservation goals and objectives for migrant waterfowl in the mid-continent have often been based on antiquated data or conjecture, and significant information needs remain with respect to migrational ecology (UMRGLRJV Board 1998).

In 1986, the United States and Canadian governments endorsed the North American Waterfowl Management Plan (NAWMP) as a framework for continental waterfowl and wetlands conservation (Canadian Wildlife Service and U.S. Fish and Wildlife Service 1986). The NAWMP develops and implements habitat management programs called “joint ventures” that promote sustainability and growth of waterfowl populations at a continental scale through partnerships of federal, state and private conservation organizations (Canadian Wildlife Service, U.S. Fish and Wildlife Service, and Secretaria de Medio Ambiente y Recursos Naturales 2004). The Upper Mississippi River and Great Lakes Region Joint Venture (hereafter, JV) develops and implements conservation strategies for waterfowl and wetlands in the upper Midwest.

The JV relies on migratory focus areas, such as the Illinois River valley, to meet foraging requirements of 8.9-million waterfowl during a 30-day fall migration period (UMRGLRJV Board 1998). However, waterfowl arrive and depart Illinois wetlands throughout fall, resulting in considerable turnover in fall populations. The length of time spent at these stopovers is largely unknown, and represents a key uncertainty in conservation planning and an explicit target for evaluation (UMRGLRJV Board 1998). Indeed, the JV employs an energy-based carrying capacity strategy to guide conservation planning, but this strategy currently employs antiquated estimates of stopover duration to estimate the number of energetic waterfowl use-days required

to attain population objectives (*sensu* Prince 1979, Reinecke et al. 1989). The most cited study was conducted over 40 years ago and used a banding method with a limited scope of inference (Bellrose and Crompton 1970). A more recent study of pintails has employed the powerful method of satellite telemetry, but the cost of this method limits findings to a small number of individuals of one species (Miller et al. 2005).

However, the dabbling duck guild includes several species that must be accounted for when planning and managing. Indeed, the JV manages all dabbling ducks comprehensively under its energetic carry capacity model due to similar habitat requirements across the foraging guild (Bellrose 1980, UMRGLRJV Board 1998). A method of studying stopover duration that captures the variation among species, gender, and age has thus far remained unavailable. Improved techniques to estimate stopover duration in all dabbling ducks at meaningful spatial and temporal scales should yield results beneficial to conservation planning and implementation. We believe radar technology offers an effective means of addressing this need.

Radar of many types has been used for decades to detect, monitor, and quantify bird movements (Eastwood 1967, Richardson 1979, Larkin 1991, Bruderer 1997). Weather surveillance radars, in particular, have been especially effective in detecting bird movements and quantifying the density of airborne flocks over large geographic areas (Nisbet 1963, Gauthreaux 1970, 1992, Williams et al. 1977, Gauthreaux and Belser 1998, Koistinen 2000, Larkin et al. 2002, Diehl et al. 2003). The modern WSR-88 D network (Weather Surveillance Radar 1988 Doppler), or next generation radar (NEXRAD), coupled with recent software and hardware developments, has great potential for the study of migration in birds at large spatial extents (Gauthreaux et al. 2003).

There are 154 of these WSR-88D units distributed across the United States, most with more

than 10 years of archived data (Figure 1). These radars scan the sky 24-hours per day at 10-minute intervals, measuring both reflectivity and radial velocity. Reflectivity is the amount of echo caused by distributed targets, such as rain, insects or birds (Diehl and Larkin 2004). Radial velocity describes a target's speed toward or away from the radar.

Unlike visual, telemetry, and local radar, NEXRAD units have the ability to continuously monitor movement patterns of flying animals during an entire season (Gauthreaux et al. 2003, Diehl and Larkin 2004, Larkin 2005). When wetland complexes are sufficiently isolated, it is possible to connect duck targets on WSR-88D with their specific source habitat. Thus, images captured by this system offer the first means of approaching comprehensive, objective census of nearly all ducks departing discrete wetland complexes. Using these censuses we developed an empirical method of estimating stopover duration in the entire dabbling duck guild

## **Methods**

***Study Site*** —We estimated stopover duration at the wetland complex that included Chautauqua National Wildlife Refuge (CNWR) and the surrounding bodies of Clear Lake, Rice Lake, Big Lake, Goose Lake, Emiquon, and Duck Creek (Figure 2). Located in Mason County, Illinois, CNWR is considered the most important waterfowl refuge in the Illinois River Valley with respect to use, and has been designated a Globally Significant Bird Area (Havera 1999). This complex has supported an average of 3.5 million duck-use-days each fall over the last 5 years (2002-2006; Michelle Horath, personal communication). We have also begun analysis of the Illinois River complex that includes Crane Lake, Jack Lake, Grass Lake, Stewart Lake, and Cuba Island (Figure 2). This complex has supported an average of 2.8 million duck-use-days each fall over the last 5 years (2002-2006; Michelle Horath, personal communication).

***Aerial inventories***—We compiled duck abundance data for fall 2005 and 2006 (October-December) for the CNWR complex from weekly INHS aerial inventories. We characterized total stopover use as duck-use-days (DUDs), which we calculated by multiplying mean number of individuals observed on 2 consecutive censuses by number of days between those counts (Rundle and Fredrickson 1981).

***Radar emigration survey***—We analyzed Level II WSR-88D data collected at the KILX radar in Lincoln, Illinois and obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center to estimate the number of waterfowl emigrating from each study site throughout the fall migration in 2005 and 2006 (October-December). We estimated the size of departing flocks when total echo had stabilized, following the ascent of takeoff, and prior to dispersion or joining of flocks from other stopover areas (Diehl and Larkin 2004).

***Target discrimination***—We discriminated ducks from weather, insects, bats and other birds based on spatial reflectivity signatures, flight speed and altitude, circadian and circannual patterns, source habitat, and strength and distribution of echo (Russell and Wilson 1996).

***Ground truthing***—We employed portable x-band radar to ground truth departure events of target (ducks) and non-target species (blackbirds) from the CNWR complex. After identifying emigrating flocks of ducks on radar we converted the amount of echo to bird abundances. Initially we have extrapolated published estimates of radar cross sections (RCS) for other bird taxa to determine an approximate RCS for dabbling ducks (Diehl and Larkin 2003). We applied this estimate of the RCS for dabbling ducks to known specifications of the radar to develop a linear formula to estimate the density of birds in departing flocks (Gauthreaux and Belser 1998, Black and Donaldson 1999).



**Analysis**—We estimated the average stopover duration across an entire migration by dividing estimates of total use-days by the total number of ducks departing the same site as estimated by radar for each site and year.

## Results

Aerial inventories indicated that the CNWR complex supported approximately 3,704,468 DUDs in 2005, and 3,574,975 DUDs in 2006. Using WSR-88D we detected 20 departure events from the CNWR complex in 2005 totaling approximately 401,758 dabbling ducks (Figure 3), and 23 departure events in 2006 totaling approximately 601,968 ducks (Figure 4). We used the following equation to estimate average stopover duration in both years based on the DUDs derived from aerial inventories and the total turnover derived from radar monitoring:

$$\text{Stopover Duration}_{\text{YR}} = \text{Total Use-days}_{\text{Aerial Surveys}} / \text{Total emigrants}_{\text{Radar}}$$

$$\text{Stopover Duration}_{2005} = 3,704,468 \text{ UD} / 401,758 \text{ ducks}$$

$$\text{Stopover Duration}_{2005} = 9 \text{ days}$$

$$\text{Stopover Duration}_{2006} = 3,574,975 \text{ UD} / 601,968 \text{ ducks}$$

$$\text{Stopover Duration}_{2006} = 6 \text{ days}$$

These initial calculations indicate that the duration of stopover among dabbling ducks in the fall was substantially shorter than 28-day estimate used for JV mid-migration objectives (Bellrose and Crompton 1970, UMRGLRJV Board 1998). However, these estimates must be refined to provide accurate data for JV management models. We intend to improve the robustness of these estimates by explicitly measuring the radar cross section of dabbling ducks. This will improve our ability to more accurately quantify the number of ducks in a flock. We will also perform ground truthing using night vision technology and portable radar to confirm methods used to identify ducks from other targets (e.g. passerines). Finally, we plan to increase

the level of replication and examine interannual variation through analysis of additional years.

### **Modeling Waterfowl Migration Using Radar Imagery**

One of the most fascinating components of migratory behavior in birds is the control of the timing of departures. It is clear now from field work, genetic analyses, and laboratory experiments that departure decisions are based on a suite of factors including endogenous circannual rhythms, energetics, and exogenous factors such as weather encountered en route and at the take-off point and destination (Berthold 2001). These factors likely interact to produce the variability in departure timing that exists among taxa, sex, age, body condition, and season.

Laboratory experiments have clearly demonstrated that endogenous factors play a great role in some species at some times of the year, however there is evidence indicating proximate environmental cues such as weather can be the dominant driver in some species at certain times of year (Richardson 1990, Zehnder et al. 2001). In general, the likelihood of take off is assumed to be affected in an additive way by responses to various distinguishable aspects of weather acting as proximate factors (Drury and Keith 1962). The magnitude of the effect of these specific weather factors on departure remains unknown for many avian taxa.

Wind has the strongest and most intuitive relationship with bird movements due to the dominant effect that it can have on the energetic costs of flight (Alerstam 1979). It is estimated that birds migrating selectively on nights with favorable winds decrease their migration time by 30% (Liechti and Bruderer 1998). Many birds tend to takeoff in peak numbers when winds are following relative to their own flight direction (Lack 1960, Richardson 1990) with light speeds (Koistinen 2000). In addition to surface conditions, wind conditions aloft likely also play a large role in emigration probability (Schaub et al. 2004).

Many avifauna also respond to barometric pressure. A comprehensive study by Nisbet and Drury (1968) found low pressure to be an important predictor of the intensity of spring migration. In contrast, fall migration is more closely associated with high pressure (Danhardt and Lindstrom 2001). In general, both spring and fall movements have been shown to be more associated with pressure trend than pressure per se (Wege and Raveling 1983, Ying 1985), with spring migrations often occurring with falling pressure, and fall migratory movements occurring with rising pressure (Ying 1985, Akesson et al. 2002).

Temperature also appears to play a role in the volume of migration occurring on any given day. Many studies have indicated that peak spring migration of birds in general tends to occur on warm days, and peak fall migration on cold days (Gauthreaux 1977, Zalakevicius 1990, Ying 1985). This behavior likely has direct selective advantages, with some birds responding directly to temperature cues when initiating flight. Alerstam (1978) found that the most consistent measure of temperature correlated with various bird groups was the trend in daily minimum temperature, while Able (1973) found it to be the 24-hour change in temperature.

There is also a strong relationship between migration intensity and precipitation. Studies employing visual observation of departures (Danhardt and Lindstrom 2001), capture-recapture (Schaub et al. 2004), radar (Gauthreaux 1977, Alerstam 1979, Hussell 1981), radio-telemetry (Wege and Raveling 1983), and release of birds aloft at night (Demong and Emlen 1978) have shown a strong negative relationship between precipitation and bird migration. For this reason, precipitation is likely second only to wind in determining the intensity of migration (Alerstam 1981). Mechanisms for the negative relationship between bird migration and precipitation include: disorientation, increased weight, and heat loss (Richardson 1978).

Like other weather factors, cloud cover is highly correlated with precipitation, but for many species overcast conditions alone are not sufficient to reduce birds aloft (Richardson 1978). Many studies indicate that some birds are capable of migrating under solid overcast, with little disorientation (Emlen and Demong 1980, Able 1985). Overall though, overcast conditions appear to be unfavorable for bird movements in general (Richardson 1990). This may be due in part to the importance of visual celestial cues in nocturnal orientation (Akesson et al. 2001). Similarly, horizontal visibility can also negatively affect the number of animals aloft (Koistinen 2000).

Waterfowl are one family of birds whose specific interaction with weather has been examined for decades with great interest. Nonetheless, quantitative estimates of factors influencing migratory movements in most waterfowl have generally eluded biologists. There is little doubt that weather variables such as cold temperatures and wind play critical roles in stimulating departure of waterfowl from staging areas, but few research efforts have successfully estimated the effect-size of such environmental factors on egress of waterfowl (Rowan 1929, Hochbaum 1955, Bellrose and Sieh 1960, Bellrose 1973, Owen 1968, Erskine 1971, Blokpoel et al. 1975, Richardson 1978, Blokpoel and Gauthier 1980).

Bellrose (1973) modeled waterfowl migration movements in relation to 33 weather-related covariates over 21 years. However, the departures in his study were derived indirectly from changes in abundances among weekly counts of ducks, making it difficult to discern egress if birds departed and arrived simultaneously.

Beason (1978) modeled waterbird migration events in relation to weather variables in the southwestern U.S. using visual observation and L-band radar. Migration events were well correlated with weather variables during spring, but poorly so during fall (Beason 1978).

However, inclement weather is rare in the southwestern U.S. during fall and low variability of independent variables resulted in low prediction power. Furthermore, these findings were based only on 2 years of migration (Beason 1978).

Cox and Afton (2000) developed models that predicted well interregional movements of radio-marked Northern Pintails (*Anas acuta*) in Louisiana, thus showing that high-resolution data on waterfowl movements could yield models with high predictive ability. However, they could not discern a consistent effect of weather-related variables on winter movements among 3 years. Furthermore, transmitters may cause birds to migrate abnormally (Miller et al. 2005).

In spite of the many attempts, few studies have isolated strong relationships between weather and migratory movements. This could be attributed in many cases to a lack of data demonstrating explicit departure events. The advent of modern weather surveillance radar has provided a tool that captures definitive migratory events and provides novel insight into the timing of departure relative to environmental covariates.

## **Methods**

***Study Site*** —We examined departure events from 3 wetland complexes in Illinois:

1) Chautauqua National Wildlife Refuge and the surrounding bodies of Clear Lake, Rice Lake, Big Lake, Goose Lake, Emiquon, and Duck Creek, 2) the Illinois River complex of backwater lakes that includes Crane Lake, Jack Lake, Grass Lake, Stewart Lake, and Cuba Island, and 3) Clinton Lake (Figure 2).

***Radar Data Analysis***—We examined Level II WSR-88D data collected at the KILX radar in Lincoln, Illinois from October 1-December 31, 2005-2006 to determine the timing of dabbling duck departures from each of the 3 sites (Figure 3 and Figure 4). Details of the radar data analysis including target discrimination are described above.

***Weather Data Collection***—We explored all of the weather data available within the region of our study site and compiled a database of surface weather observations collected in Springfield, Illinois including: wind direction and speed, cloud cover, visibility, temperature, and barometric pressure. In addition to these raw variables we also calculated barometric pressure and temperature trends. The wind conditions at migratory altitude may be more relevant to departure probability, so we evaluated range height indicator displays of migrant ducks on the KILX WSR-88D and determined that dabbling ducks typically migrate from the Illinois River Valley at approximately 600 m height above ground level. We compiled wind aloft data at this altitude from the radiosonde database collected at KILX, Lincoln, Illinois. We have conducted literature reviews to determine effective methods of measuring and scaling hydrologic inundation, ice coverage on roosting wetlands, and snow coverage in foraging fields.

***Statistical Analysis***—We construct a set of competing biological models that will be analyzed using an information theoretic approach (Burnham and Anderson 1998). These include the temporal covariates of date and days since last movement along with discrete combinations of the weather variables described above. Our analyses will quantify migration based on a binary response variable representing whether or not an emigration event occurred. We will use logistic regression (PROC GENMOD or PROC LOGIST; SAS Institute 2004) to model variation in daily emigration probability (Cox and Afton 2000). Competing models will be ranked according to their complexity and parsimony based on Akaike's Information Criteria (AIC, Burnham and Anderson 1998). Furthermore, we will determine the magnitude of the effects of covariates based on maximum likelihood estimation.

## **Results**

Our initial analysis of radar-derived departure data revealed a high level of synchrony in the timing of departure among dabbling ducks from independent stopover sites in the Illinois River Valley. Furthermore, the weather radar data revealed departures occurring in temporal clusters of two to three days, which corresponds with the temporal cycles of regional weather in the Midwest (Figure 3 and Figure 4). These two observations provide local, empirical evidence of a relationship between proximate environmental conditions and emigration in dabbling ducks. Our future analysis will quantify which weather conditions have the greatest effect on the probability of daily departure of ducks from stopover sites, and what the magnitude of their effect is.

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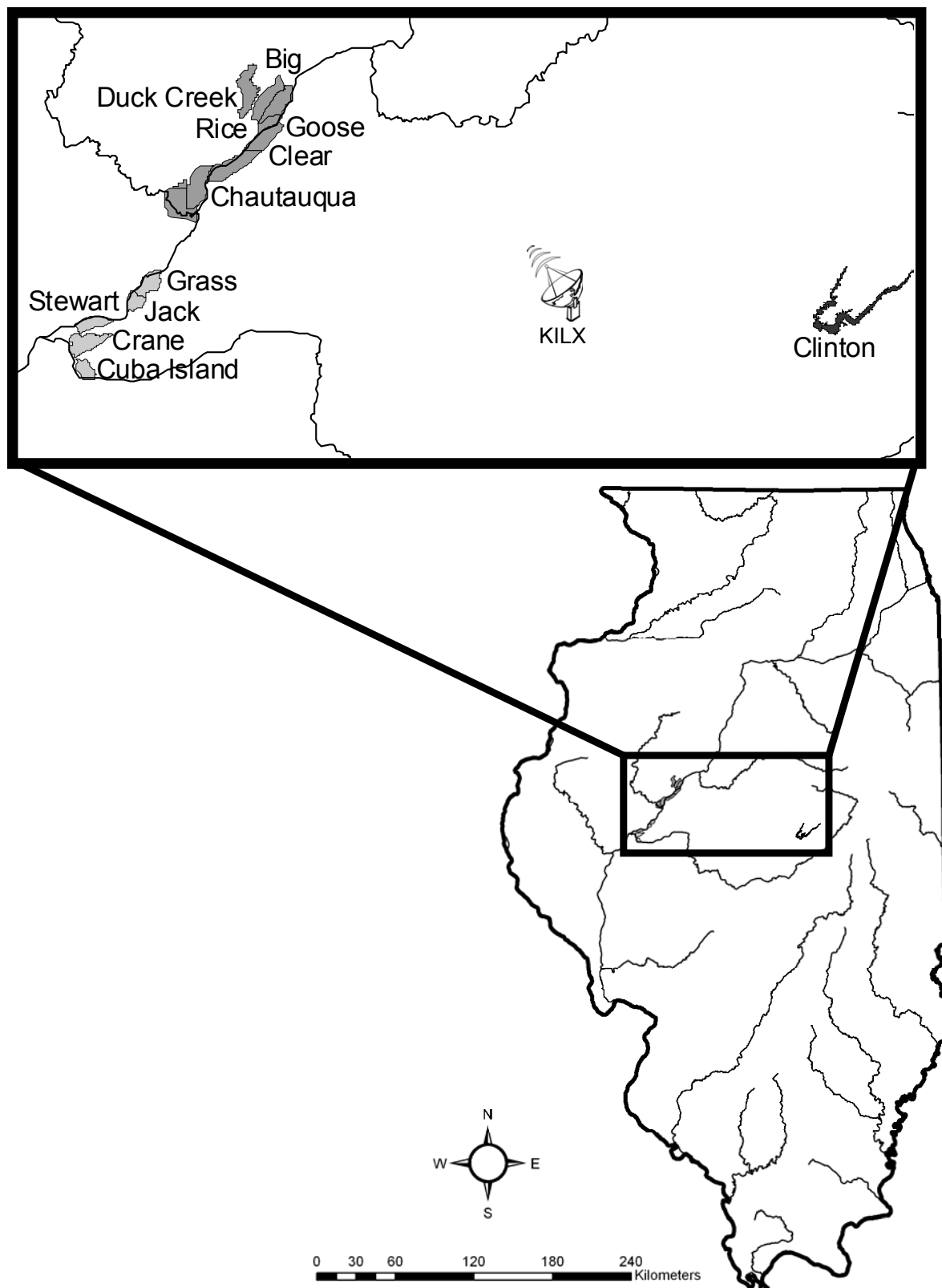


Figure 2—Two field sites for estimation of fall stopover duration in dabbling ducks, 2005-2006, and three source wetlands for dabbling duck emigration probability modeling (Clinton Lake was not included in analysis of stopover duration).

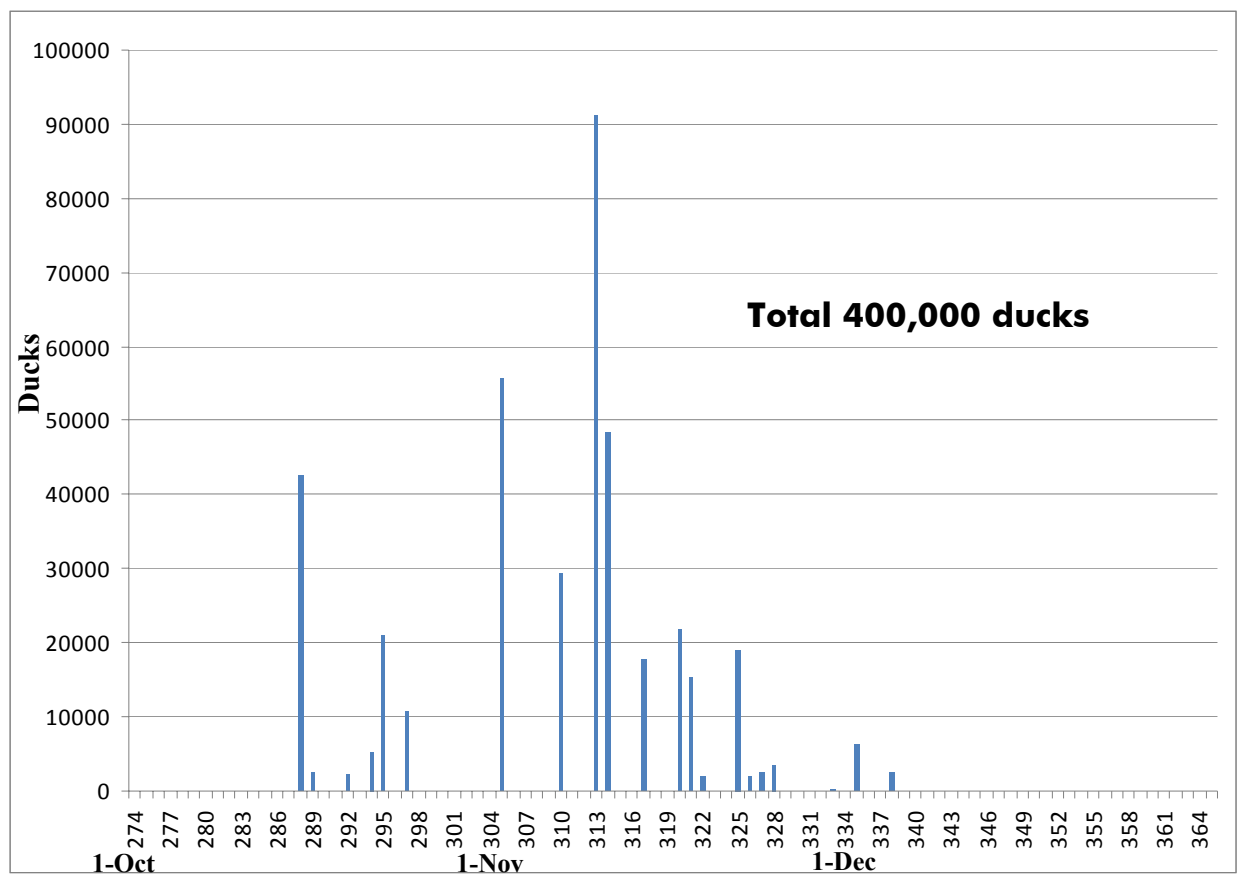


Figure 3—Emigration chronology, magnitude, and total turnover from Chautauqua National Wildlife Refuge Complex, 2005.



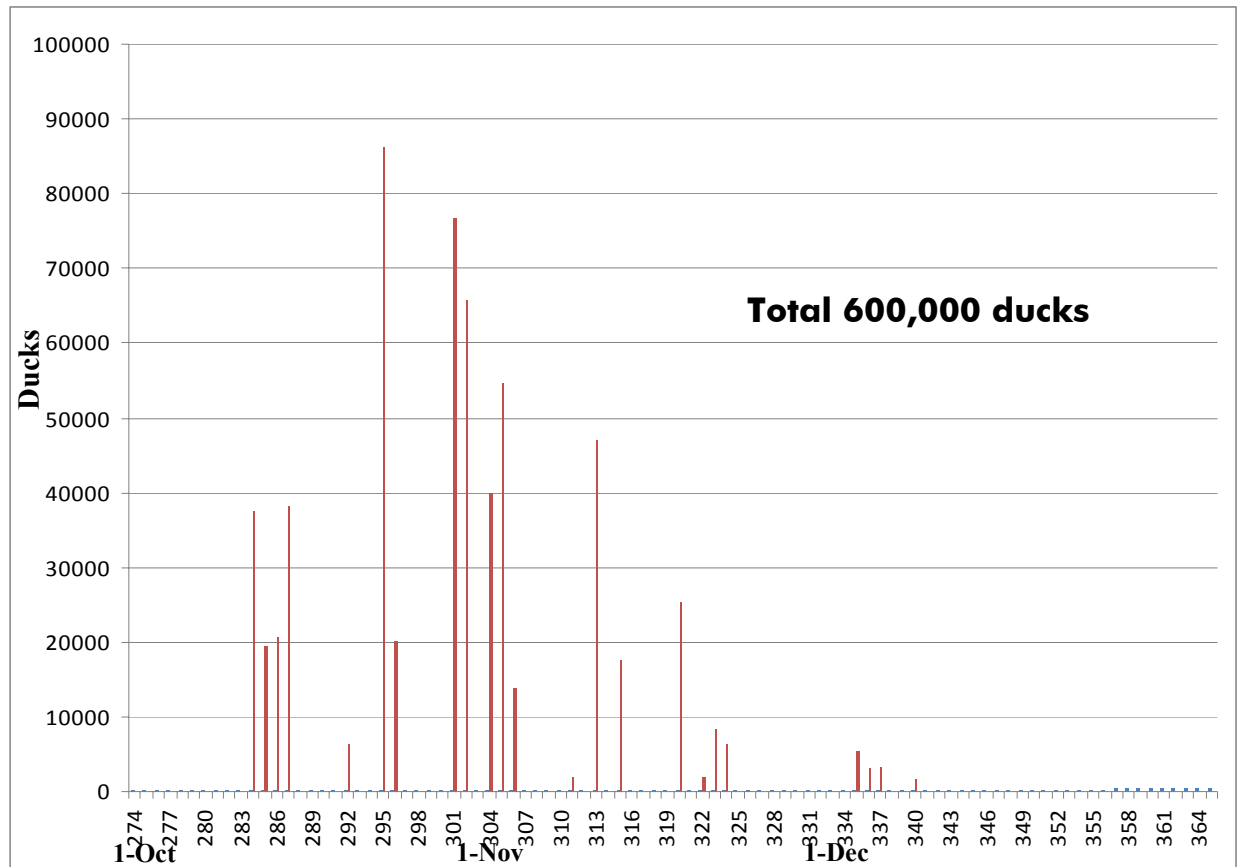


Figure 4—Emigration chronology, magnitude, and total turnover from Chautauqua National Wildlife Refuge Complex, 2006.